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The Game Model of Blue Carbon Collaboration along MSR—From the Regret Theory Perspective

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Abstract: Ocean pollution and global warming are two pressing environmental problems exacerbated by human economic behavior. Building a blue carbon cooperation platform along the Maritime Silk Road (MSR) to promote sustainable development of countries along the route is of practical value to solving these two problems. Based on the analysis and review of the latest research on blue carbon, cooperative game and MSR, Weber's law and regret theory are introduced to establish an economic model of blue carbon international cooperation, which proves the economic feasibility of blue carbon cooperation along MSR. The influence of psychological factors on the decision making of blue carbon international cooperation is also discussed. In addition, the measures to promote international cooperation are also discussed according to the current situation of marine blue carbon resources.

Keywords: blue carbon; Maritime Silk Road; regret theory; cooperation game

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1. Introduction

Since the 21st century, marine pollution and climate warming, two pressing global environmental problems, have increasingly attracted global attention. In 2014, the United Nations Environment Assembly listed marine plastic waste pollution as one of the top 10 pressing environmental problems, and at the G20 Osaka Summit in 2019, the "Blue Ocean Vision" was adopted, pledging to achieve "zero discharge" of plastic waste in the ocean by 2050. At the same time, human economic behavior continues to worsen the phenomenon of environmental pollution, such as the annual discharge of a large amount of domestic and industrial sewage by coastal countries to the sea, the dumping of pollutants by ships to the sea, a large amount of pollution caused by offshore oil exploration, and serious marine pollution caused by unreasonable offshore engineering construction and marine development [1].

To reduce carbon emissions and increase the drawdown of atmospheric carbon, many countries have paid increasing attention to blue carbon, which can help capture and store carbon by coastal ecosystems as a strategy to achieve their Nationally Determined Contributions [2]. A decade of scientific research has shown that blue carbon is the most effective carbon sink for carbon fixation and storage [3,4]. Blue carbon refers to the processes, activities and mechanisms of using ocean activities and marine organisms to absorb carbon dioxide from the atmosphere, and to fix and store it in the ocean. The most effective "blue carbon ecosystems" are seagrass bed, mangrove and salt marsh, while macroalgae, shellfish and even micro-organisms have also made outstanding contributions to carbon fixation and storage [5,6]. It has been shown that the destruction of blue carbon resources, which make up only 2 to 6% of the combined area of tropical forests, will result in about 19% more carbon emissions than deforestation [7]. About one-third of mangroves, seagrasses and salt marshes in countries along the world's coastline have already begun to degrade or disappear and are likely to do so as global economic growth accelerates [8]. Blue carbon cooperation is one of the effective ways to solve the global climate problem. It can be understood as a common idea or joint action that can provide a unique framework, policy interventions and financial support to manage and restore blue carbon ecosystems and to stop the release of plastics into marine ecosystems at local, regional and global scales. For example, blue carbon sequestration is a technology that utilizes the carbon sequestration mechanisms of marine organisms and microorganisms to generate carbon sinks. Only when the international trade market is established and the appropriate measurement and pricing mechanism of carbon sink products is established, blue carbon development will become an efficient production activity with economic value in accordance with the operation law of the economic system. Moreover, marine resources have traditionally been regarded as common property. For example, high-seas fisheries, which could be used to exploit blue carbon, account for 60% of the ocean's resources. However, the high seas are not under the jurisdiction of any one country; thus, they are difficult to exploit without international cooperation [9]. Therefore, it is economically feasible and necessary to carry out international cooperation on blue carbon, and it has become an urgent historical task for countries along the Maritime Silk Road that share a common coastline to work together to solve the problems of Marine pollution and climate warming.

In October 2013, President Xi Jinping of China proposed the 21st Century Maritime Silk Road (MSR) initiative during his visit to Asean countries. This is a road where one end runs from the Chinese coast through the South China Sea and the Indian Ocean to Europe, and the other runs from the Chinese coast through the South China Sea to the South Pacific. Thus, China will be connected to the Persian Gulf and Mediterranean Sea through Central Asia and the Indian Ocean. The strategic goal of the MSR is to build the economic integration of Asia, Europe and Africa. Countries along the MSR include but are not limited to Indonesia, Thailand, Malaysia, Vietnam, Cambodia, Singapore, Philippines, India, Myanmar, Laos, Bangladesh, Brunei, Sri Lanka, Pakistan, Kuwait, Saudi Arabia, Turkey, Egypt, United Arab Emirates, Yemen, Kenya, Tanzania, Greece, and Italy [10,11]. Over the past six years, fruitful achievements have been made in the construction of the MSR, with more port cooperation projects, more air routes, more liner fleets, and more cooperation projects in the fields of maritime engineering and offshore oil exploration. This has greatly improved the level of industrialization and the living standards of the people in the countries along the road. However, it has also increased the amount of marine pollution and carbon emissions, bringing new challenges to the building of a maritime community with a shared future, such as the Malacca port in Malaysia, Gwadar port in Pakistan, Piraeus port in Greece, and so on. Whether a country can adopt the international cooperation scheme of blue carbon is not only related to its economic development level and the economic benefits and values obtained from the cooperation, but it is also related to the collective IQ, the psychological model, and cultural psychological characteristics formed in the historical evolution process of a country and a nation [12]. The integration of these psychological factors into economic decision making can more truly reflect and predict the economic possibility of blue carbon international cooperation and provide a more scientific theoretical basis for the establishment of a blue carbon international cooperation mechanism.

The remainder of the paper is organized as follows. Section 2 summarizes the latest research results of blue carbon, cooperative game and MSR, which lays a theoretical foundation for the establishment of the blue carbon cooperation model of the MSR. In Section 3, based on the introduction of Weber's law and regret theory, the regret theory model is combined with the cooperative game model to establish the economic model of blue carbon international cooperation, and the model is proven. Section 4 analyzes and discusses the psychological variables of Regret Theory and Weber's law, collects data of national blue carbon resources, tests the data of the model, proves the rationality of the model, summarizes the influence mechanism, and processes the psychological variables in blue carbon international cooperation. Section 5 discusses the measures to promote international cooperation based on the current situation of marine blue carbon resources.

2. Literature Review

"Blue Carbon: the Role of Healthy Oceans in Binding Carbon—A Rapid Response Assessment", issued in 2009 by the United Nations Environment Program (UNEP), Food and Agriculture Organization of the United Nations (FAO) and United Nations Educational, Scientific and Cultural Organization (UNESCO) Intergovernmental Oceanographic Commission, is one of the most comprehensive achievements in the field of blue carbon research [13]. The report makes a comprehensive analysis and demonstration from six aspects, including carbon fixation, ocean and climate, the role and current situation of "blue carbon", the significance of "blue carbon" to human society and the way to change. It also proposes the establishment of a global "blue carbon sink fund", the "blue carbon sink" benchmark and standard, and a coordination and financial support mechanism. However, the report did not demonstrate the economic feasibility of international cooperation on blue carbon, nor did it provide a specific mechanism for sharing the benefits.

To become an economic product, blue carbon sequestration needs to be quantitatively evaluated and exchanged. Over the past 30 years, Indonesia has lost 40% of mangroves due to the development of aquaculture, resulting in annual carbon emissions ranging from 0.07~0.21 $PgCO_2e$ [14], while the global mangrove carbon stocks could increase by nearly 10% by 2115 due to increased tropical rainfall if mangrove deforestation were halted [15]. Furthermore, researchers studied the impact of land use change caused by mangrove shrimp conversion on bulk density, organic carbon concentration and storage of sediments along the Red Sea coast of southern Saudi Arabia [16]. In addition, research has been carried out to investigate the main role of marine vegetation in the marine carbon cycle and to evaluate the carbon storage of marine vegetation sediments [17]. Besides, the amount of carbon dioxide released into the atmosphere was estimated when the blue carbon ecosystem degraded, and it was concluded that the carbon dioxide emission range from 0.15 to 1.02 million tons per year [18]. Recently, Rogers et al. proposed a concise evaluation framework for blue carbon survival, storage and sustainability, and the incorporated socio-economic factors into the evaluation system [19]. These studies have provided a methodological reference for the economic value evaluation of blue carbon sequestration and have proven that blue carbon sequestration is an economic product that can be quantitatively measured.

As a commodity, the economy of blue carbon can also be effectively produced and managed. For example, Garrard and Beaumont studied the effects of ocean acidification on seagrass bed carbon storage and integration [20]. In addition, Lovelock et al. put forward a risk assessment framework for carbon dioxide emissions caused by soil degradation and constructed the form of carbon value for carbon sink management [21]. There was also a research study on the coastal carbon sink management that proposed more specific management methods and measures [1]. Some countries have implemented blue carbon projects, and good results have been obtained. For example, four projects have been developed in Kenya, India, Vietnam and Madagascar [22]. The financing methods, outcomes and policy implications of each project have been discussed and studied. These individual cases have yielded good environmental and economic benefits and informed broader international climate policy discussions, negotiations and cooperation, which could make it easier for countries with rich blue carbon to protect and restore coastal wetlands and reduce carbon emissions.

The research of Chinese scholars mainly focuses on mangroves, algal beds, blue carbon sinks, coastal ecosystems, marine carbon sinks, coastal ecosystems, carbon markets, etc. [15,23,24]. The most authoritative scholar in this field is academician Jiao Nianzhi of Xiamen University, and he pointed out that China's vast sea area, rich biodiversity, abundant industrial foundation and sound scientific research conditions have laid a solid foundation for the development of blue carbon. He also insisted that the development of blue carbon is of strategic significance to China's social and economic development and ecological civilization construction. Other scholars have studied the development of blue carbon in China from different perspectives. For example, Wang analyzed the Belt and Road initiative and the development in controlling greenhouse gas emissions in Guangdong province, as well as suggested the paths and measures for the province to develop blue carbon [25]. In addition, Zhang and Wang elaborated on the mechanism and policy of blue carbon cooperation in countries along the MSR [26]. Moreover, Zhou et al. evaluated the carbon sink potential of China's "blue carbon ecosystem" and put forward corresponding improvement measures [27]. Besides, Shen and Liang analyzed the pricing of blue carbon sequestration by using the cost pricing model, providing a basis for blue carbon trading [28]. The existing research results on MSR blue carbon cooperation provide a reference for the construction of economic models. However, due to the differences in cultures, development modes and political systems, MSR countries are affected by different psychological models in the process of economic decision making. Therefore, it is necessary to introduce new theory to improve the traditional cooperative game model.

In conclusion, the decision making of countries along the MSR on blue carbon cooperation is influenced by their economic, cultural, and psychological perceptions; as a commodity with economic attributes, blue carbon can be analyzed by an economic model.

3. Model and Method

According to Weber's law, the same stimulus must differ by a certain proportion in order to cause different sensations. Economic variables are stimuli to blue carbon decision makers. Only when the difference of such stimulus reaches the threshold of decisionmakers' awareness can it arouse the attention of the decision makers and then change the strategies and take action.

Furthermore, some scholars introduced psychological theories into economics and proposed regret theory [29]. On the premise of abandoning the axiom of independence, they incorporated regret and joy into the preference relationship of individual risk decision making and established the expression form of non-transitive binary utility function and the axiomatic system of regret theory. Regret is described as the emotion generated by comparing the outcome or condition of a given event with the state to be selected. According to regret theory, decision makers have limited rationality and seek to minimize potential regret [30]. With multidimensional preference and incomplete weight information, some researchers studied regret theory-based group decision making [31], while Diecidue and Somasundaram put forward the central axiom to weight consistency, making regret theory observable at the individual level [32]. Regret theory combines economic and psychological theories and takes regret and joy into account when analyzing decision makers' behaviors, which improves decision theory under uncertain conditions. Different countries have different regret values and regret coefficients; thus, regret theory is considered in this model.

Thus, according to the theoretical analysis, the assumptions of this study can be made as follows.

3.1. Assumptions of Income Function

The production of blue carbon depends on the biochemical activities of marine organisms and microorganisms to convert carbon dioxide from the air into organic carbon and store it in the ocean. "The blue carbon report" confirms the crucial role of blue carbon ecosystems such as seagrass beds, mangroves and salt marshes, in mitigating global climate change and the carbon cycle [13]. In addition, the coastal ecosystem will be affected by land-based carbon sinks, resulting in a decrease in carbon sequestration efficiency. Poor maintenance of algae, beach wetlands, mangroves and marine aquaculture, which requires funding, also leads to the decline of carbon sinks. Therefore, it can be assumed that the economic factors of blue carbon production are mainly land, capital and carbon fixation technology, and the cost is mainly the investment in initial environmental treatment, which can be regarded as a fixed value and is represented by B in this paper.

In addition, blue carbon production is an economic production activity whose price is determined by the estimated price in the international carbon sink market and has a certain stability in the short term. Meanwhile, in blue carbon international cooperation trading, the price is based on the negotiated contract, and the negotiated price remains unchanged during the contract period; thus, the price is assumed to be a fixed value P.

The production of blue carbon requires increasing the area of blue carbon resources such as mangroves, seagrass beds and salt marshes. Conversely, the expansion of the acreage of carbon sink fishery can also increase the blue carbon sink. Therefore, carbon sink output is related to the input ocean area [33]. At the same time, capital needs to be invested in the remediation of land ecosystems, the maintenance of algae, mangrove and salt marsh, as well as the measurement and monitoring of carbon sinks. The greater the capital investment, the higher the carbon sink output efficiency. The production of blue carbon sink is similar to that of industry and agriculture; thus, it can be assumed that the production function of blue carbon sink conforms to the Douglas function. Thus, its basic form is shown in Equation (1):

$$Y = AL^{\alpha}K^{\beta} \tag{1}$$

where L is the effective utilization area of the blue carbon ecosystem of the country in this study, and K is the capital input of the country.

Let B be the total cost of environmental governance inputs in MSR countries, and B_i be the total cost of environmental governance inputs in MSR country i, then, $v_i = PY_i - B = \sum B_i, i = \{1, 2, 3, \ldots, n\}$

Then, the corresponding revenue function is:

$$W = PY - B = PAL^{\alpha}K^{\beta} - B \tag{2}$$

where α, β are positive values; when $\alpha + \beta = 1$, the economy of scale of input factors remain unchanged. Then, the return function of a single country in blue carbon cooperation can be set as:

$$v_i = PY_i - B_i = PA_iX_i{}^{\alpha}Y_i{}^{\beta} - B_i \tag{3}$$

where A_i represents the blue carbon technology level of the country i, X_i represents the effective utilization area of the blue carbon ecosystem of the country i, Y_i represents the capital input of country i, X_i, $Y_i > 0$, and $\alpha \in (0, 1)$, $i = \{1, 2, 3, \ldots, N\}$ represents countries along the MSR.

3.2. Setting of Participants in Cooperative Games

As MSR countries are the subjects of international blue carbon cooperation, they are taken as the main research objects. Therefore, the participants of the blue carbon cooperation game are the countries along the MSR and China. The main directions of MSR are west and south. The western route runs from China's coastal ports through the South China Sea and the Indian Ocean to Europe. There are 41 countries along the route, while the southern route starts from China's coastal ports and crosses the South Pacific to Oceania. There are four countries along the route [34]. As shown in Table 1, the number of participants in MSR blue carbon cooperation is $N = 46$.

The distribution of blue carbon resources and the investment in blue carbon research are different in these countries. Therefore, there are differences in blue sink production technology in each country. When MSR countries negotiate a cooperation agreement, the countries along the route can share the production technology of blue carbon sink and use more efficient blue carbon technology for production, thus achieving more economic benefits [35].

Table 1. Countries along the MSR.

Region	Number of Countries	Included Countries
Asian	10	Singapore, Indonesia, Thailand, Malaysia, Vietnam, Laos, Cambodia, Brunei, Philippines, Myanmar
Oceania	2	Australia, New Zealand, Papua New Guinea, Fiji
South Asia	5	India, Sri Lanka, Bangladesh, Maldives, Pakistan
West Asia	15	Turkey, Jordan, Lebanon, Israel, Palestine, Yemen, UAE, Saudi Arabia, Oman, Qatar, Iran, Iraq, Syria, Kuwait, Bahrain
Africa	11	Egypt, Sudan, Libya, Algeria, Tunisia, Morocco, Kenya, Somalia, Eritrea, Djibouti, Tanzania

3.3. Suppose Coefficient Weber

Blue carbon cooperation along the MSR is an economic cooperation [36]. The cooperation mechanism and resource allocation are mainly market mechanisms. The market-related variables and the perceived sensitivity to income loss will influence the Weber coefficient. When the concept of sustainable development has been recognized by MSR countries, sustainable development and environmental protection will be an important basis for economic decision making. In order to simplify the model design and facilitate the solution and analysis, it is assumed that the Weber coefficient c of the MSR countries is consistent and homogeneous.

The regret theory can be expressed by the following perceived utility function:

$$U(X) = v(x) + r(v(x) - v(y))$$

where $r(v(x) - v(y))$ is the regret value R mentioned below.

3.4. Cooperative Game Model

Bulleted lists resemble this: Let the set $N = \{1, 2, 3 \ldots\ n\}$, and for any $s \subset N$, call s a union of N. For the set of countries along the MSR, $N = \{1, 2, 3, \ldots, 77\}$, given the set N, there are ordered pairs (N, v), where the feature function v is the mapping from $2^{\mathrm{I}} = \{s \mid s \subset \mathrm{I}\}$ to real number set; that is (N, v): $2^N \to R^n$, and satisfies

$$v(\phi) = 0 \tag{4}$$

$$v(s_1 \cup s_2) \geq v(s_1) + v(s_2) \tag{5}$$

For any s_1, satisfies

$$s_1 \cap s_2 = \varnothing \tag{6}$$

where s is any kind of cooperation in n-person set and $v(s)$ is the return of cooperation s.

When Equation (5) holds, there is a solution set for cooperative games. Let z_i denote the return that member i of $\phi_i(v)$ should be obtained from the maximum return v (n) of cooperation. $z = [z_1, z_2, z_3 \cdots z_n]$ is the distribution or core of the cooperative game. It meets

$$Z(s) - Z(s \backslash 1) \tag{7}$$

$$Z_i \geq v_i \tag{8}$$

According to Equations (7) and (8), n-person cooperative game has countless solutions. In a cooperative game, not all solutions are stable. In the n-person cooperative game, in order for the alliance structure to enable all participants to benefit from the alliance and achieve cooperation, it is required to meet the effectiveness:

$$\sum_{i\varepsilon n} Z_i = V(N) \tag{9}$$

The stable solution must take into account the allocations of each player and the allocations of each sub alliance. If any sub-alliance is not satisfied with the allocations, it is possible to leave the alliance; that is, the alliance cooperation will be stable only if the following conditions are met,

$$\sum_{i\varepsilon n} Z_i \geq V(S), \forall S \in N \tag{10}$$

Based on Equations (9) and (10), the allocations in the core meet not only the individual rationality, but also the alliance rationality; that is, the income of any alliance is not less than the income it can obtain independently from the allocations in the core [37].

3.5. Shapley Value of the Cooperative Game of MSR Countries

Shapley value expression is as follows (Zhao et al., 2020b):

$$\phi_i(v) = \sum_{S \subset I} \frac{(|S|-1)!(n-|S|)!}{n!}[v(S) - v(S \backslash i)], i = 1, 2, \ldots n \tag{11}$$

Combined with the previous assumptions, V_n represents the total return of blue carbon production in countries along MSR, then

$$V_n = \sum_i^n v_i = \sum_i^n \left(PA_i X_i{}^a Y_i{}^{1-a} - B_i\right) \tag{12}$$

V_c is used to represent the overall return of the consortium. Because when the countries along MSR join a coalition, they will be able to share blue carbon technology and engage in production according to what works best. Then,

$$V_c = PAmax\left(\sum_i^n X_i\right)^a \left(\sum_i^n Y_i\right)^{1-a} - B, X_i \geq 0, Y_i \geq 0, i \in \{1, 2, 3, \ldots n\}, a \in (0, 1) \tag{13}$$

Wang et al. believed that regret utility function is the product of the difference between the perceived parameters and the attribute values of the two schemes [38]. However, given Weber's findings, only a certain percentage of the same amount of stimulus difference leads to sensation. According to Weber's theorem, the critical condition for regret about not participating in cooperation is

$$\frac{V_c - V_n}{V_c} = c \tag{14}$$

which is

$$V_c - \frac{V_n}{1-c} = 0 \tag{15}$$

Only

$$V_c - \frac{V_n}{1-c} > 0 \tag{16}$$

the participant will regret it, whose value is R; that is, the country chooses to cooperate. The perceptual parameter is Weber constant, and then

$$R = c\left(V_c - \frac{V_n}{1-c}\right) \tag{17}$$

Otherwise the regret value is zero. This study only discusses the situation when

$$V_c - \frac{V_n}{1-c} > 0.$$

The Shapley value is a solution based on the objective basis that people are perfectly rational. However, people in reality are often bounded in rationality. The effect of psychological expectations on the existence of cooperative games solutions is no longer that cooperative return is greater than non-cooperative return (ABC), but that cooperative return is greater than the sum of non-cooperative return and regret value.

$$V_c \geq V_n + R \tag{18}$$

Bring Equation (17) into Equation (18) and sort it out

$$\frac{(1-c)^2}{1-2c}V_c \geq V_n \tag{19}$$

For a single player i, Formula (19) can be turned into

$$\frac{(1-c)^2}{1-2c}\phi_i \geq V_i \tag{20}$$

Considering the conditional Formula (5) for the existence of cooperative game solutions, substituting (19), (20) into (11), the Shapley value of the blue carbon cooperation of the MSR countries can be obtained:

$$\phi_i{}'(v) = \frac{(1-c)^2}{1-2c}\sum\nolimits_{S\subset I}\frac{(|S|-1)!(n-|S|)!}{n!}[v(S)-v(S\backslash i)], i = 1,2,\ldots,77 \tag{21}$$

According to Equation (21), it can be inferred that the larger the sea area suitable for blue carbon production, the higher the capital invested in environmental governance, the larger the output value of blue carbon sinks; thus, the greater the Shapley value of cooperation, the more conducive to attracting MSR countries to join the cooperative alliance. Countries with advanced blue carbon production technology will share technology, and the higher the carbon sink return of the participating countries, the more stable the blue carbon cooperation.

4. Discussion and Simulation of Blue Carbon Cooperation Game Solution along the MSR

4.1. Discussion on the Blue Carbon Cooperation Game Solution of the MSR

According to the model assumptions, the prerequisite for stable cooperation of the alliance is $\frac{(1-c)^2}{1-2c}V_c \geq V_n$. If the solution to a cooperative game with only two players exists, then it follows that a solution to a cooperative game with N players also exists. The solution and proof of the cooperative game between two players are as follows:

$$\frac{(1-c)^2}{1-2c}PAmax(X_1+X_2)^a(Y_1+Y_2)^{1-a} - B \geq PA_1X_1{}^aY_1{}^{1-a} + PA_2X_2{}^aY_2{}^{1-a} - B \tag{22}$$

Among them, $Amax \geq A_1$, $Amax \geq A_2$, may wish to make $A_1 \geq A_2$, and then the above formula can be transformed into

$$\frac{(1-c)^2}{1-2c}A_1(X_1+X_2)^a(Y_1+Y_2)^{1-a} \geq A_1X_1{}^aY_1{}^{1-a} + A_2X_2{}^aY_2{}^{1-a} \tag{23}$$

Divide both sides of the inequality by $A_1(X_1+X_2)^a(Y_1+Y_2)^{1-a}$ to obtain

$$\frac{(1-c)^2}{1-2c} \geq \frac{X_1{}^aY_1{}^{1-a}}{(X_1+X_2)^a(Y_1+Y_2)^{1-a}} + \frac{A_2}{A_1}\frac{X_2{}^aY_2{}^{1-a}}{(X_1+X_2)^a(Y_1+Y_2)^{1-a}} \tag{24}$$

Assuming that

$$u_1 = \frac{X_1}{(X_1+X_2)}, v_1 = \frac{Y_1}{(Y_1+Y_2)}, u_2 = \frac{X_2}{(X_1+X_2)}, v_2 = \frac{Y_2}{(Y_1+Y_2)} \tag{25}$$

where $u_1 + u_2 = 1,\ v_1 + v_2 = 1$.

Equation (23) can be simplified as:

$$\frac{(1-c)^2}{1-2c} \geq u_1{}^av_1{}^{1-a} + \frac{A_2}{A_1}u_2{}^av_2{}^{1-a} \tag{26}$$

Make $f = {u_1}^a {v_1}^{1-a} + \frac{A_2}{A_1} {u_2}^a {v_2}^{1-a}$, which is

$$f = {u_1}^a {v_1}^{1-a} + \frac{A_2}{A_1}(1-u_1)^a(1-v_1)^{1-a} \tag{27}$$

and equals to

$$f = x^a y^{1-a} + \frac{A_2}{A_1}(1-x)^a(1-y)^{1-a} \tag{28}$$

where $x, y \in [0,1]$.

Take the partial derivative of x and y, respectively

$$\frac{\partial f}{\partial x} = a x^{a-1} y^{1-a} - \frac{A_2}{A_1} a(1-x)^{a-1}(1-y)^{1-a} \geq 0 \tag{29}$$

$$\frac{\partial f}{\partial y} = (1-a) x^a y^{-a} - \frac{A_2}{A_1}(1-a)(1-x)^a(1-y)^{-a} \geq 0 \tag{30}$$

It can be obtained that f has a maximum value at $(1,1) : f_{max} = 1$.

Which is $\frac{(1-c)^2}{1-2c} \geq 1$, obtaining $c \leq \frac{1}{2}$, and from the definition of Weber constant, $c > 0$. In summary, $0 < c < \frac{1}{2}$.

If psychological expectations and the Weber coefficient are considered, only when the Weber coefficient of the MSR countries is within the range between 0 and 0.5, the Shapley value of cooperative game will exist, and the international cooperation of blue carbon can be achieved.

4.2. Simulation of Blue Carbon Cooperation Game along the MSR

The cooperative game model above shows that MSR countries can independently benefit from the development of a blue carbon economy through alliance and cooperation. Among the countries along MSR, Indonesia has the largest distribution of blue carbon resources and the fastest disappearing rate of blue carbon. Economic development has the greatest impact on blue carbon sink. China is the country with the most leading research on blue carbon technology, and Malaysia is geographically connected with Indonesia and China [39]. Moreover, the three countries have the most complete data on blue carbon sequestration; thus, the cooperation of the three countries is taken as an example to test the scientificity and rationality of the model.

4.2.1. Data and Assumptions

Assumptions regarding national capital and technological level blue carbon land inputs are shown in Appendix A.

To keep the dimensions consistent, it is assumed that the initial input cost of each country is 1/10,000 of its GDP. Two data of input cost in China are given as B_1 = 0, B_1 = 0.01% GDP = 13,610 for simulation.

4.2.2. Calculation of the Return of Blue Carbon Production in Various Countries

The blue carbon return of China's own production is

$$V_1 = A_1 {X_1}^{0.5} {Y_1}^{0.5} - B_1 = 18828.13 - B_1$$

The return of Indonesia's own production of blue carbon is:

$$V_2 = A_2 {X_2}^{0.5} {Y_2}^{0.5} - B_2 = 11434.83 - B_2$$

The return of Thailand's own production of blue carbon is:

$$V_3 = A_3 {X_3}^{0.5} {Y_3}^{0.5} - B_3 = 2580.97 - B_3$$

4.2.3. The Alliance Body Return of Pairwise Alliance

Regarding the China and Indonesia alliance, production according to China's blue carbon technology, the return is

$$V_{(1,2)} = 87954.90 - B_1 - B_2$$

For the China and Thailand Union, according to China's blue carbon technology level for joint production, the return is

$$V_{(1,3)} = 37614.80 - B_1 - B_3$$

For the Indonesian and Thai Unions, produce at two common levels of blue carbon technology, and the return is:

$$V_{(2,3)} = 14193.25 - B_2 - B_3$$

4.2.4. Return of the Three Countries Forming a Major Alliance

China, Indonesia, and Malaysia have formed a big alliance to share China's blue carbon technology for production. The benefits are:

$$V_{(1,2,3)} = 95144.96 - B_1 - B_2 - B_3$$

Calculate the Shapley value and sort out part of the calculation process of the three countries' cooperative game model as shown in Table 2.

Table 2. Blue carbon cooperation game revenue distribution table of China, Indonesia, and Malaysia.

s	**1**	**1,2**	**1,3**	**1,2,3**
$v(s)$	$18828.13 - B_1$	$87954.90 - B_1 - B_2$	$37614.80 - B_1 - B_3$	$95144.96 - B_1 - B_2 - B_3$
$v(s\backslash 1)$	0	$11434.83 - B_2$	$2580.97 - B_3$	$14193.25 - B_2 - B_3$
$v(s) - v(s\backslash 1)$	$18828.13 - B_1$	$76520.07 - B_1$	$35033.83 - B_1$	$80951.71 - B_1$
$\|s\|$	1	2	2	3

This article uses the first country, China, as an example to simulate the improved Shapley value. The simulation results are shown in Figures 1 and 2:

when $B_1 = 0$

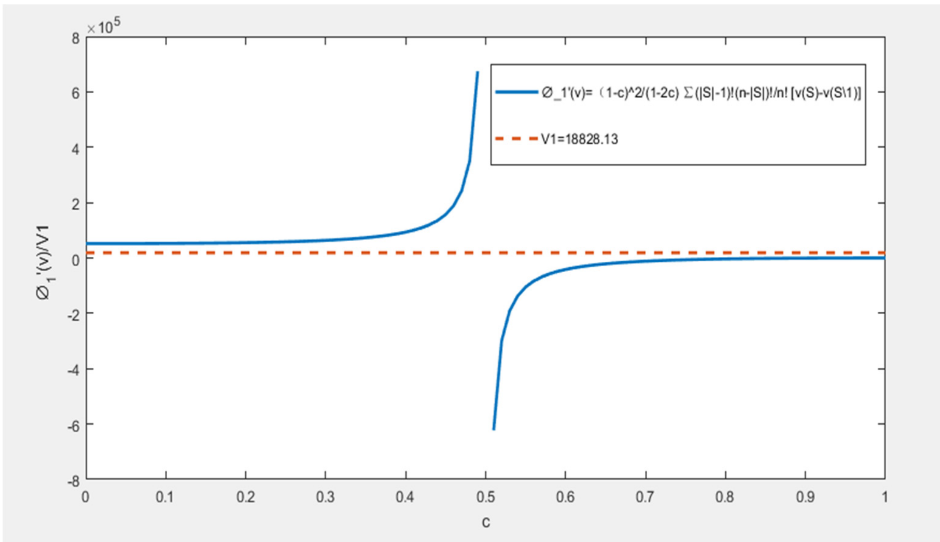

Figure 1. The Shapley value of China as an example.

when B_1 = 13,610

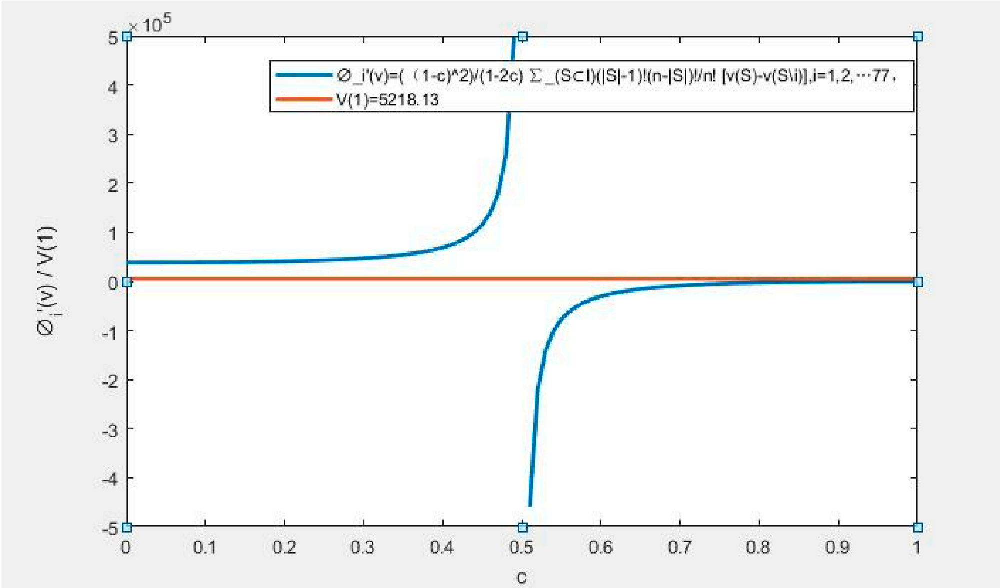

Figure 2. The improved Shapley value of China as an example.

From the simulation results, when c belongs to (0, 0.5), the Shapley value is greater than the return of China's own production, especially when (0.4, 0.5).

In the actual blue carbon international cooperation, the cultural differences, physiological characteristics and resource differences of MSR countries lead to differences in economic perception of Weber coefficient among countries. The Weber coefficient for some countries could be between 0.5 to 1, which would make the sharp value non-existent, and these countries may not join the blue carbon national cooperation. Therefore, in order for more MSR countries to participate in the international cooperation of blue carbon, in addition to reasonable economic measures, comprehensive measures should be taken in cultural, political and psychological aspects to reduce the Weber coefficient of relevant countries.

5. Discussions and Conclusions

5.1. Discussion

There are some interesting findings of this study that are worth discussing.

First, a country's economic strategy is stable and will not change easily. Countries will adjust and change their economic strategy only when the changes in perceived and perceived benefits reach a certain proportion. It is believed that policymakers will only feel the difference in return when the absolute return exceeds a certain threshold, as determined by the Weber coefficient [36]. Then, they will be prompted to change their economic strategy. Different countries have different regret values and regret coefficients. The difference of regret coefficient may lead to the non-existence of a Shapley value. Without the coordinated solution of cooperative game equation, blue carbon cooperation cannot be realized.

Second, the Weber coefficient is a proportional parameter. The smaller the initial income of MSR countries participating in the cooperation, the more attention will be paid by decision makers to small changes in the income value of MSR countries, which may lead to adjustments and changes of strategy. Countries with smaller economic scale and a lower development stage are more likely to join the blue carbon cooperation alliance if they can benefit from the blue carbon cooperation.

Third, regret values and Weber coefficients measure the psychological changes caused by economic changes that lead to changes in emotion and behavior. Different cultures have different value orientations; thus, their regret value and psychological evaluation of economic added value are also different. Confucianism and Buddhism emphasize spiritual values and individual well-being, and countries influenced by Confucianism and

Buddhism have higher Weber coefficients and regret thresholds. Market-driven countries place more emphasis on economic value and individual achievements. These countries have a relatively small Weber coefficient, and economic stimulus is more likely to cause them to change strategy.

Fourth, from the perspective of the relationship between cooperative game theory and the field of climate change dynamics, Ciano et al. provided a set of competitive negotiations and unified competitive solutions for cooperative games [37]. They analyzed balanced and super-balanced games from two central results related to cooperative game methods, and their model provides a theoretical basis for our research. In order to simplify, we used the core of cooperative game in the process of constructing the model in this paper, which improved the stability and feasibility of the model.

Fifth, blue carbon sequestration production technology level is an important parameter that causes the change of carbon sequestration output value and economic income of a country. Some countries have advanced technologies to effectively protect or restore the blue carbon region. Through cooperation, they can obtain advanced technologies for blue carbon production, and then obtain more output and benefits [9]. This will make countries with low development level and relatively backward technology willing to adopt cooperation strategy, which is conducive to the international cooperation of blue carbon.

Sixth, it is believed that cultural psychology evolved over time, and a country's economic regret value and Weber coefficient change over a long period of time, which is related to cultural exchange, strong cultural influence and social integration. Therefore, the blue carbon cooperation in MSR countries can be promoted by spreading advanced culture and promoting the concept of sustainable development.

Finally, among the MSR countries, the most abundant blue carbon resources are found in East Asia. Meanwhile, mangrove, seagrass beds, and salt marshes are also among the most degraded and damaged areas. East Asian countries and China are geographically close, economically connected and culturally similar. They have similar economic awareness sensitivity and Weber coefficients. Therefore, this region can be regarded as a key area for blue carbon cooperation along MSR.

5.2. Practical Implications

This study also provides some policy implications for China to promote blue carbon cooperation along MSR.

First, China has taken a leading position in blue carbon research, technology, management and policy regulation in recent years. It can actively advocate and build a platform for the exchange of scientific research, technology and management experience, and attract MSR countries to join the "blue carbon cooperation" through technology sharing and policy exchange.

Second, China should strengthen cultural exchanges with MSR countries, promote the green and sustainable economic development pattern, and share the experience of sustainable development with the countries along the MSR. It should encourage relevant countries to change their way of thinking in economic development and guide MSR countries to give greater weight to marine environmental protection in decision making, so as to reduce its Weber coefficient.

Third, it is proposed to protect the economic and ecological environment of various countries and promote the construction of a community of marine destiny through a reasonable blue carbon resource allocation mechanism [36]. When launching the MSR blue carbon cooperation project, China is suggested to give priority to developing countries with smaller economies that are close to each other to carry out cooperation, establish the demonstration project of blue carbon cooperation of the MSR, and then promote it to other countries along the route to continuously increase the number of alliance countries and promote the maritime lucky community of the MSR.

Fourth, China should pay attention to environmental protection when investing in infrastructure in MSR countries, especially in protecting and restoring the bottom line of blue carbon resources. It is strongly suggested to pay attention to protect the blue carbon resources in MSR countries in port investment, offshore oil exploration and offshore construction. It is also believed that coastal mangroves, salt algae, seagrass beds and other marine ecosystems could help countries along the route to achieve green and sustainable development.

5.3. Conclusions

To sum up, the regret factor of the MSR countries affects the achievement of blue carbon cooperation agreement among MSR countries. Only within the given threshold range, will the Shapley value of the cooperative game exist, and the blue carbon cooperation agreement of the MSR countries can be reached. In addition, due to the differences in culture, economic development level, economic system and political system of the countries along the MSR, the regret coefficient is also different. The difference of regret coefficient makes the Shapley value of blue carbon cooperative game meet the existing conditions, and it is difficult to reach a cooperation agreement. The greater the cultural, political and economic differences, the more difficult it is to reach an alliance agreement. Our research only considers psychological and economic factors, and other factors should be the foci of future works. Moreover, in the blue carbon cooperation along the MSR, it is highly unlikely that all countries will participate in the main alliance, but sub-alliance groups of multiple countries exist. For example, in establishing the South China Sea blue carbon cooperation platform, countries with close regional, cultural, institutional and economic exchanges should be selected for consultation, and a sub-alliance should be formed first, and then other countries should be attracted to join.

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Appendix A

Table A1. Variables of countries along the MSR.

Countries \ Variable	Technical Level	National Capital Inputs (USD Million)	Blue Carbon Land Inputs
China	1	136,100	2604.69 km^2
Indonesia	0.5	10,420	50,194 km^2
Malaysia	0.5	3540	7527.6 km^2

References

1. Crooks, S.; Herr, D.; Tamelander, J.; Laffoley, D.; Vandever, J. *Mitigating Climate Change through Restoration and Management of Coastal Wetlands and Near-Shore Marine Ecosystems: Challenges and Opportunities*; World Bank Environment Department: Washington, DC, USA, 2011; Volume 20, p. 11.
2. Seddon, N.; Sengupta, S.; García-Espinosa, M.; Hauler, I.; Herr, D.; Rizvi, A.R. *Synthesis and Recommendations for Enhancing Climate Ambition and Action by 2020 Nature-Based Solutions in Nationally Determined Contributions*; IUCN: Gland, Switzerland; University of Oxford: Oxford, UK, 2019.
3. Fourqurean, J.W.; Duarte, C.M.; Kennedy, H.; Marbà, N.; Holmer, M.; Mateo, M.; Apostolaki, E.T.; Kendrick, G.A.; Krause-Jensen, D.; McGlathery, K.J.; et al. Seagrass ecosystems as a globally significant carbon stock. *Nat. Geosci.* **2012**, *1*, 297–315. [CrossRef]
4. Nehren, U.; Wicaksono, P. Mapping soil carbon stocks in an oceanic mangrove ecosystem in Karimunjawa Islands, Indonesia. *Estuar. Coast. Shelf Sci.* **2018**, *214*, 185–193. [CrossRef]
5. Kennedy, H.; Beggins, J.; Duarte, C.M.; Fourqurean, J.W.; Holmer, M.; Marbà, N.; Middelburg, J.J. Seagrass sediments as a global carbon sink: Isotopic constraints. *Glob. Biogeochem. Cycles* **2010**, *24*, 6696–6705. [CrossRef]
6. Atwood, T.B.; Connolly, R.M.; Ritchie, E.G.; Lovelock, C.E.; Heithaus, M.R.; Hays, G.C.; Fourqurean, J.W.; Macreadie, P.I. Predators help protect carbon stocks in blue carbon ecosystems. *Nat. Clim. Change* **2015**, *5*, 1038–1045. [CrossRef]
7. Nie, X.; Chen, X.; Li, F.; Wang, H. Research on marine blue carbon hot spots and frontier trends at home and abroad—Visual analysis based on CiteSpace 5.1. *Ecol. Econ.* **2018**, *34*, 38–42, 63.
8. Waycott, M.; Duarte, C.M.; Carruthers, T.J.B.; Orth, R.J.; Dennison, W.C.; Olyarnik, S.; Calladine, A.; Fourqurean, J.W.; Heck, K.L., Jr.; Randall Hughes, A.; et al. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 12377–12381. [CrossRef]
9. Zhao, C.; Xu, X.; Fang, C.; Yang, Y.; Gong, Y. Feasibility study on blue carbon cooperation in the South China Sea from the perspective of cooperative game. *China Popul. Resour. Environ.* **2020**, *30*, 66–72.
10. Schinasa, O.; Westarp, A.G. Assessing the impact of the maritime silk road. *J. Ocean. Eng. Sci.* **2017**, *2*, 186–195. [CrossRef]
11. Song, A.Y.; Fabinyi, M. China's 21st century maritime silk road: Challenges and opportunities to coastal livelihoods in ASEAN countries. *Mar. Policy* **2022**, *136*, 104923. [CrossRef]
12. Kaitala, V.; Lindroos, M. Sharing the benefits of cooperation in high seas fisheries: A characteristic function game approach. *Nat. Resour. Modeling* **1998**, *11*, 275–299. [CrossRef]
13. China Ocean NewsBlue. Carbon Report: Providing a new perspective for emission reduction. *China Ocean. News* **2016**, *3*, 9–11.
14. Alongi, D.M.; Murdiyarso, D.; Fourqurean, J.W.; Kauffman, J.B.; Hutahaean, A.; Crooks, S.; Lovelock, C.E.; Howard, J.; Herr, D.; Fortes, M.; et al. Indonesia's blue carbon: A globally significant and vulnerable sink for seagrass and mangrove carbon. *Wetl. Ecol. Manag.* **2016**, *24*, 3–13. [CrossRef]
15. Sanders, C.J.; Maher, D.T.; Tait, D.R.; Williams, D.; Holloway, C.; Sippo, J.Z.; Santos, I.R. Are global mangrove carbon stocks driven by rainfall? *J. Geophys. Res. Biogeosci.* **2016**, *121*, 2600–2609. [CrossRef]
16. Eid, E.M.; Arshad, M.; Shaltout, K.H.; El-Sheikh, M.A.; Alfarhan, A.H.; Picó, Y.; Barcelo, D. Effect of the conversion of mangroves into shrimp farms on carbon stock in the sediment along the southern Red Sea coast, Saudi Arabia. *Environ. Res.* **2019**, *176*, 108536. [CrossRef] [PubMed]
17. Nellemann, C.; Corcoran, E.; Duarte, C.M.; Valdés, L.; De Young, C.; Fonseca, L.; Grimsditch, G. *Blue Carbon. A UNEP Rapid Response Assessment*; United Nations Environment Program, GRID-Arendal: Arendal, Norway, 2009; pp. 45–50.
18. Pendleton, L.; Donato, D.C.; Murray, B.C.; Crooks, S.; Aaron Jenkins, W.; Sifleet, S.; Craft, C.; Fourqurean, J.W.; Boone Kauffman, J.; Marbà, N.; et al. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. *PLoS ONE* **2012**, *7*, e43542. [CrossRef] [PubMed]
19. Rogers, K.; Macreadie, P.I.; Kelleway, J.J.; Saintilan, N. Blue carbon in coastal landscapes: A spatial framework for assessment of stocks and additionality. *Sustain. Sci.* **2019**, *14*, 453–467. [CrossRef]
20. Garrard, S.L.; Beaumont, N.J. The effect of ocean acidification on carbon storage and sequestration in seagrass beds: A global and UK context. *Mar. Pollut. Bull.* **2014**, *86*, 138–146. [CrossRef]
21. Lovelock, C.E.; Atwood, T.; Baldock, J.; Duarte, C.M.; Hickey, S.; Lavery, P.S.; Masque, P.; Macreadie, P.I.; Ricart, A.M.; Serrano, O.; et al. Assessing the risk of carbon dioxide emissions from blue carbon ecosystems. *Front. Ecol. Environ.* **2017**, *15*, 257–265. [CrossRef]
22. Wylie, L.; Sutton-Grier, A.E.; Moore, A. Keys to successful blue carbon projects: Lessons learned from global case studies. *Mar. Policy* **2016**, *65*, 76–84. [CrossRef]
23. Lu, W.; Qiu, T.; Du, L. A study on influence factors of carbon emissions under different economic growth stages in China. *Econ. Res. J.* **2013**, *48*, 106–118.
24. Chen, F.; Zhang, J.; Zhou, S.; Wang, J.; Wang, J. Research progress of carbon trade in China. *J. Anhui Agric. Sci.* **2013**, *41*, 3579–3581.
25. Wang, C. Research on the development of blue carbon in Guangdong Province under the background of the 21st century Maritime Silk Road. *Mar. Dev. Manag.* **2017**, *34*, 39–43.
26. Zhang, W.; Wang, M. Research on National Blue Carbon Cooperation Mechanism along the Maritime Silk Road. *Econ. Geogr.* **2018**, *38*, 25–31, 59.
27. Zhou, C.; Mao, Q.; Xu, X.; Fang, C.; Luo, Y.; Li, B. Preliminary analysis of carbon sequestration potential of blue carbon ecosystem in China's coastal zone. *Chin. Sci. Life Sci.* **2016**, *46*, 475–486.

28. Shen, J.; Liang, R. Study on blue carbon sequestration pricing of marine ranch. *Resour. Sci.* **2018**, *40*, 1812–1821. [CrossRef]
29. Zhang, S.; Ye, J. A Review of the Theory of Regret. *Syst. Eng.* **2009**, *27*, 45–50.
30. Loomes, G.; Sugden, R. Regret theory: An alternative theory of rational choice under uncertainty. *Econ. J.* **1982**, *92*, 805–824. [CrossRef]
31. Zhang, S.; Zhu, J.; Liu, X.; Chen, Y. Regret theory-based group decision-making with multidimensional preference and incomplete weight information. *Inf. Fusion* **2016**, *31*, 1–13. [CrossRef]
32. Diecidue, E.; Somasundaram, J. Regret theory: A new foundation. *J. Econ. Theory* **2017**, *172*, 88–119. [CrossRef]
33. Cullis-Suzuki, S.; Pauly, D. Failing the high seas: A global evaluation of regional fisheries management organizations. *Mar. Policy* **2010**, *34*, 1036–1042. [CrossRef]
34. Li, X. Analysis of investment environment of countries along the 21st century Maritime Silk Road. *Acad. Explor.* **2017**, *4*, 73–81.
35. Zhao, C.; Xu, X.; Gong, Y.; Fan, H.; Chen, H. Blue Carbon Cooperation in the Maritime Silk Road with Network Game Model and Simulation. *Sustainability* **2019**, *11*, 2748. [CrossRef]
36. Zhao, C.; Fang, C.; Gong, Y.; Lu, Z. The economic feasibility of Blue Carbon cooperation in the South China Sea region. *Mar. Policy* **2020**, *113*, 103788. [CrossRef]
37. Ciano, T.; Ferrara, M.; Gangemi, M.; Merenda, D.S.; Pansera, B.A. Climate Change Sustainability: From Bargaining to Cooperative Balanced Approach. *Games* **2021**, *12*, 45. [CrossRef]
38. Wang, X.; Wang, L.; Zuo, Z. Review of Regret Theory and its application in travel. *J. Wuhan Univ. Technol. Traffic Sci. Eng. Ed.* **2018**, *42*, 231–237, 242.
39. Partnerships in Environmental Management for the Seas of East Asia (PEMSEA). Understanding Strategic Coastal Blue Carbon Opportunities in the Seas of East Asia. 2017. Available online: http://pemsea.org/publications/reports/coastal-blue-carbon-east-asia (accessed on 11 November 2021).